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The Change of Form with Age in the Dairy Cow

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The Change of Form With Age in the Dairy Cow

SAMUEL BRODY AND A. C. RAGSDALE

ABSTRACT.—Data are presented showing that the growth of the dairy cow is accompanied by a change of conformation. Forty figures, based on twenty-one linear measurements, are presented showing the *relative* changes in form from birth to practical maturity. Many significant changes were found to exist. The calf has relatively longer legs, greater height at croup, a very much shorter body, and is more rectangular in form than the cow. The mature cow is proportionately very much broader and deeper throughout the hind quarters, and this may be correlated with milk secretion and the reproductive functions.

Change of form is, next to increase in weight, the most significant feature characterizing growth. From a practical standpoint, the utility of the dairy cow is no doubt associated with her conformation or form. From a theoretical standpoint a knowledge of the quantitative changes of form with age are of interest in leading to an insight into the mechanisms bringing about the changes of form with age and with weight so as to produce for each age and weight an animal best fitted to its physical and biological environment. Because of its physical, mathematical, and biological phases, this problem has interested men of different viewpoints from Galileo to Thompson¹.* In spite, however, of the practical and theoretical interest of this subject, relatively few quantitative investigations on the changes of form with growth are available, especially as they relate to domestic animals, and particularly to the dairy cow. The purpose of this bulletin is to present some results obtained from a study of the quantitative changes of form with age in the dairy cow.

The data on which this study is based have been accumulating in this department for some time in connection with studies relating to normal growth and the effect of the age of first calving and the liberality of the food supply on the growth of the dairy heifer. The methods of measurements and other experimental details of this investigation were formulated by Eckles and carried on by Eckles, Swett, and their associates in this department. The experimental details of the measurements have been described by Eckles and Swett². The responsibility for the development of the viewpoint presented in this paper—the idea of studying the change of form of the cow with age—and for the compilation of the data from the original data sheets, as well as all the computations, charting, and interpretation of the charts, rests with the author.

*Refers to the list of references on page 7.

The experimental details may be summarized by stating that twenty-one linear measurements were taken of dairy cows at monthly intervals during the first 60 months of extra-uterine life. The animals under observation consisted of Jersey, Holstein, and Ayrshire cattle. Each breed was divided into sub-groups, one classed as normal growth and others according to the age of first calving and the liberality of the ration they received. For the present purpose the averages for all the sub-groups were used.

The description of the measurements and the numbers by which these measurements have come to be known are shown in Table 1.

TABLE 1.—THE LINEAR MEASUREMENTS AND THE NUMERALS BY WHICH THEY HAVE COME TO BE KNOWN

1.	Height at withers.
2.	Height at highest point of croup.
3.	Height at hip points.
4.	Depth of chest just behind elbow point.
5.	Width of chest just behind elbow point.
6.	Width of hips.
7.	Width of loin.
8.	Length from poll to point of muzzle.
9.	Width of forehead.
10.	Circumference of muzzle at opening of mouth.
11.	Length from horns to base of withers.
12.	From highest point of withers to a line between hips.
13.	From a line between hips to tail.
14.	From point of shoulders to point of hips.
15.	From point of shoulders to ischium.
16.	From point of hips to ischium.
17.	From point of hips directly forward to last rib.
18.	Heart girth just behind elbow joint.
19.	Girth of paunch at end of last rib.
20.	Smallest circumference of shin bone of fore leg.
21.	Smallest circumference of shin bone of hind leg.

The numbers of animals represented in this study are shown in Table 2. No other numerical data are given in this paper because the numerical values can be read off from the curves by means of which all data are presented. The values read off from the smoothed curves are more reliable than the original values from which the curves were plotted. This is because of the experimental and computational mistakes that may have entered in making up the individual values but which are eliminated to a considerable extent by smoothing the curves which represent the changes of the magnitudes with age.

The results of this study are represented almost entirely pictorially by means of photographs of the animals and by means of graphs. Each

photograph and graph is accompanied by a legend pointing out the significance of the pictorial representation. No other explanations, outside of this introduction and the summary, are given in the text. Each figure and legend is therefore meant to be studied and read in the same way a printed page is usually read.

In reading the figures indicating change of form with age, the reader must always keep in mind the meaning of change of form. By change of

TABLE 2.—NUMBERS OF ANIMALS REPRESENTED

Age, Mos.	I Height at withers			II Height of croup			III Height of hiv joints		IV The other 17 measurements	
	Jer- sey	Hol- stein	Ayr- shire	Jer- sey	Hol- stein	Ayr- shire*	Jer- sey	Hol- stein	Jer- sey	Hol- stein
Birth	10	11	4	7	6	2	5	6	5	6
1	14	20	5	8	8	2	6	13	6	8
2	17	23	4	9	7	2	11	14	7	7
3	18	15	4	9	7	2	11	14	7	7
4	20	23	4	9	8	2	11	15	7	8
5	22	29	5	11	8	2	11	15	7	8
6	24	36	6	15	14	2	11	20	11	14
7	29	37	6	23	19	2	14	25	17	20
8	35	39	8	25	23	2	21	25	19	22
9	34	41	8	29	22	2	22	27	21	24
10	37	41	9	30	22	2	24	23	23	22
11	39	44	9	32	24	2	27	26	24	25
12	41	47	9	32	25	2	28	27	24	25
13	41	48	10	33	25	2	27	27	24	25
14	40	46	8	30	26	2	26	28	23	26
15	42	46	7	32	27	1	27	28	24	27
16	40	47	8	35	28	1	28	30	24	28
17	36	47	8	33	29	2	28	31	23	29
18	41	47	9	34	27	2	26	29	26	27
19	43	49	9	37	30	2	29	31	26	28
20	39	49	10	40	29	3	28	30	20	28
21	40	50	11	43	28	4	30	30	30	28
22	41	49	12	42	27	4	32	30	29	27
23	41	46	10	42	26	4	32	29	30	26
24	40	43	10	40	25	4	34	28	31	24
25	36	38	6	36	22	4	33	18	28	22
26	35	40	4	33	23	4	30	19	26	23
27	37	38	8	34	23	4	28	18	26	22
28	23	35	4	29	22	4	28	19	22	22
29	24	32	4	27	19	4	23	18	21	19
30	31	34	8	26	19	4	22	10	20	19
31	20	21	4	26	18	4	21	18	21	18
32	21	17	4	24	16	4	21	16	20	16
33	30	29	8	21	17	4	20	17	17	17
34	20	16	4	23	15	4	17	15	19	15
35	19	17	4	23	17	4	19	17	19	17
36	31	30	7	22	15	4	19	15	18	15
37	18	16	5	22	15	4	18	15	18	14
38	16	15	4	20	13	4	18	12	16	13
39	17	17	4	20	13	4	16	13	16	14
40	16	16	4	20	13	4	15	13	16	13
41	16	16	3	21	12	3	16	12	16	12
42	26	29	9	19	13	4	16	13	14	13
43	15	17	2	17	13	2	14	13	15	13
44	16	13	2	18	12	2	15	12	16	12
45	17	13	4	20	12	4	16	13	16	12
46	12	14	2	14	12	2	16	12	12	12
47	13	15	2	15	12	2	12	12	13	12
48	27	26	9	19	12	4	13	12	12	12
49	13	14	2	13	11	2	13	11	11	11
50	13	10	1	15	9	1	12	9	13	9
51	11	10	1	15	9	1	13	9	11	9
52	9	10		9	9		11	9	9	9
53	9	4		9	6		9	6	9	6
54	11	14	4	7	5	1	10	5	5	5
55	66	6		5	6		6	6	5	6
56	4	4		4	4	1	4	4	4	4
57	4	3		6	5	2	4	3	4	3
58	2	5	2	4	5	2	4	5	2	5
59	4	4		4	3		2	3	3	3
60	10	4	3	5	1		3	1	4	

*And for the other measurements of the Ayrshire calves.

form is meant a change in the ratios between the rates of growth in different dimensions; or, as Thompson puts it, "Form is a ratio of magnitudes, referred to directions in space". This bulletin is then concerned with a study of the changes in the ratios between the different measurements with age.

SUMMARY

Forty charts have been presented showing that the growth of the dairy cow is accompanied by a change of form.

The conformation of the calf is adapted for efficient locomotion as is evidenced by its long legs of large cross section, and light body. The evolutionary significance of this conformation might be explained by the idea that in the natural state, the long-legged calf had a greater chance of escape and survival than the short-legged calf.

Very little growth in length of legs takes place after birth. This is explained as due to the fact that the animal grows rapidly in weight and length after birth and that further growth of the already long legs would weaken them inasmuch as the strength of a column supporting a weight varies inversely as its length. Increasing the length of the legs without a corresponding increase in cross section would, therefore, seriously weaken them. The cross section of the legs is not increased because of the clumsiness it would bring with it. The growth in length of hind legs is less than of the front legs presumably because the hind quarter is heavier than the front quarter. The calf is, therefore, a very long-legged and light-bodied animal as compared to the cow.

The conformation of the mature dairy cow is adapted for reproduction and milk secretion. Her very broad hindquarters as compared to those of the calf are directly correlated with her reproductive function. (See also measurements 12, 13, 16). She has a great capacity for handling large quantities of bulky food as compared to the calf. This is evidenced by her enormous paunch and other related measurements (See measurements 17, 12) as compared to the calf.

The above are the most significant changes in form with age. The reader will have noticed other probably less significant changes such as the relatively great increase in length of neck with age (probably of importance as an aid in feeding on pasture); the effect of gestation on stimulating the growth of some parts (e. g. measurement 12), and retarding others (e. g. measurements 11 and 13).

FOOTNOTE REFERENCES

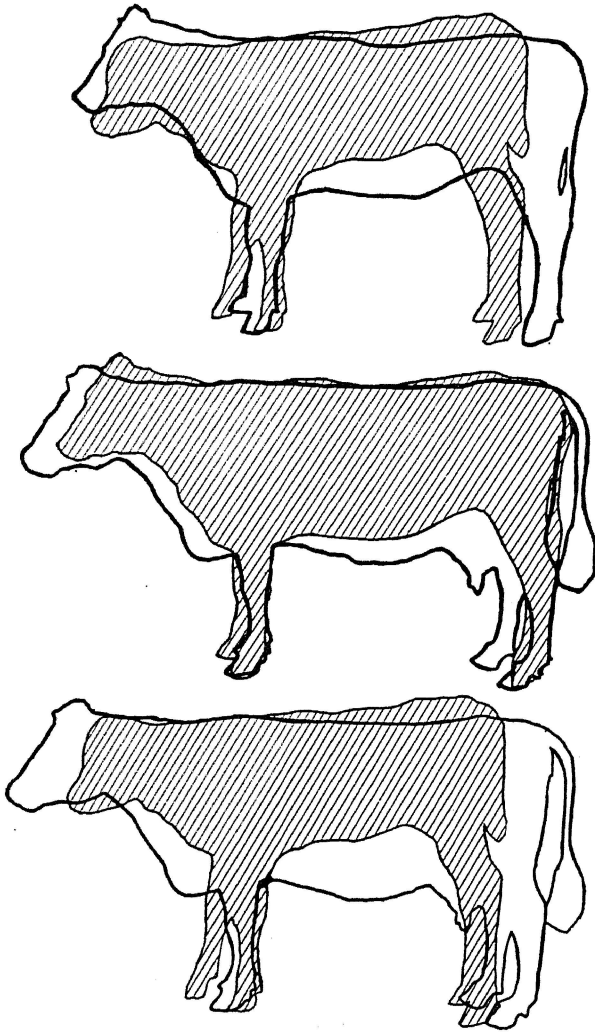
1. For an excellent discussion of the literature and the problem of change of form with age, see Thompson, D'A. W., *Growth and Form*, Cambridge, 1917.
2. Eckles, C. H. and Swett, W. W., *University of Missouri Agr. Exp. Sta. Research Bul.* 31, 1918. See also Eckles, C. H., *University of Missouri Agr. Exp. Sta. Research Bul.* 36, 1920.
3. Brody, S. and Ragsdale, A. C., *J. Gen. Physiol.*, 1924, VI, 329.
4. Davenport, C. B., *Body-Build and its Inheritance*, Publication 329 of the Carnegie Institution of Washington, 1923.
5. Brody, S. and Ragsdale, A. C., *J. Gen. Physiol.*, 1920-21, III, 623.

ACKNOWLEDGMENT

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EXPLANATION OF FIGURES

Figure 1.—Change of form with age. This is a comparison of the side views of calf, heifer, and cow reduced to the same height at withers. Note the relative heights at croup and at withers of the animals at differ-



ent ages, and compare with figures 11 and 12. Compare the relative length of body with figures 23 to 27; the relative girth of chest and paunch with figures 23 and 35; note the relative lengths of head and compare with figure 20.

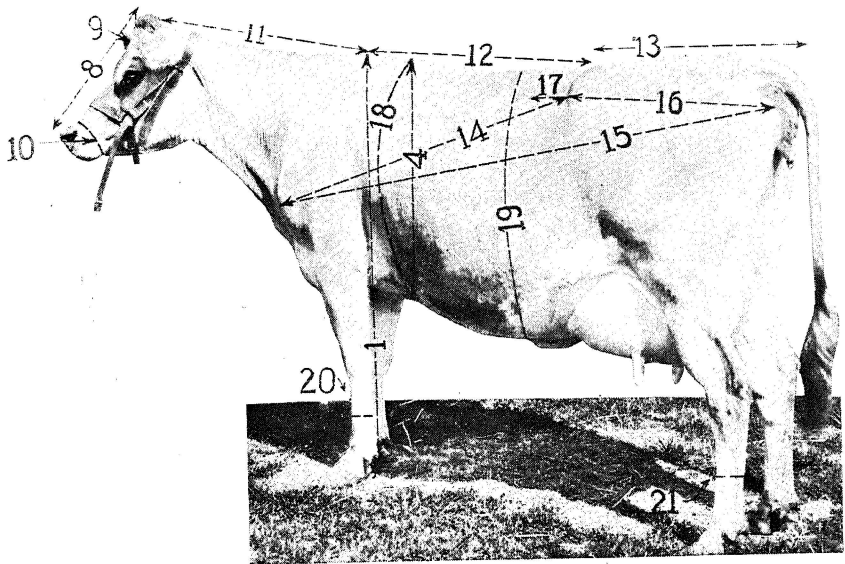


Figure 2.—The points of anatomy and the measurements taken of the cows referred to in Table 1 and in the charts.



Figure 3.—Change of form with age. A comparison of the side views of calf, heifer, and cow reduced to the same height at withers. Note the relative length of legs, body, and relative height at croup and withers at the three ages.



Figure 4.—Change of form with age. A comparison of front and rear views of cow, heifer, and calf reduced to the same height at withers and croup. Note the relative width of hips and compare with figure 16; note the relative girth of paunch and compare with figure 35.

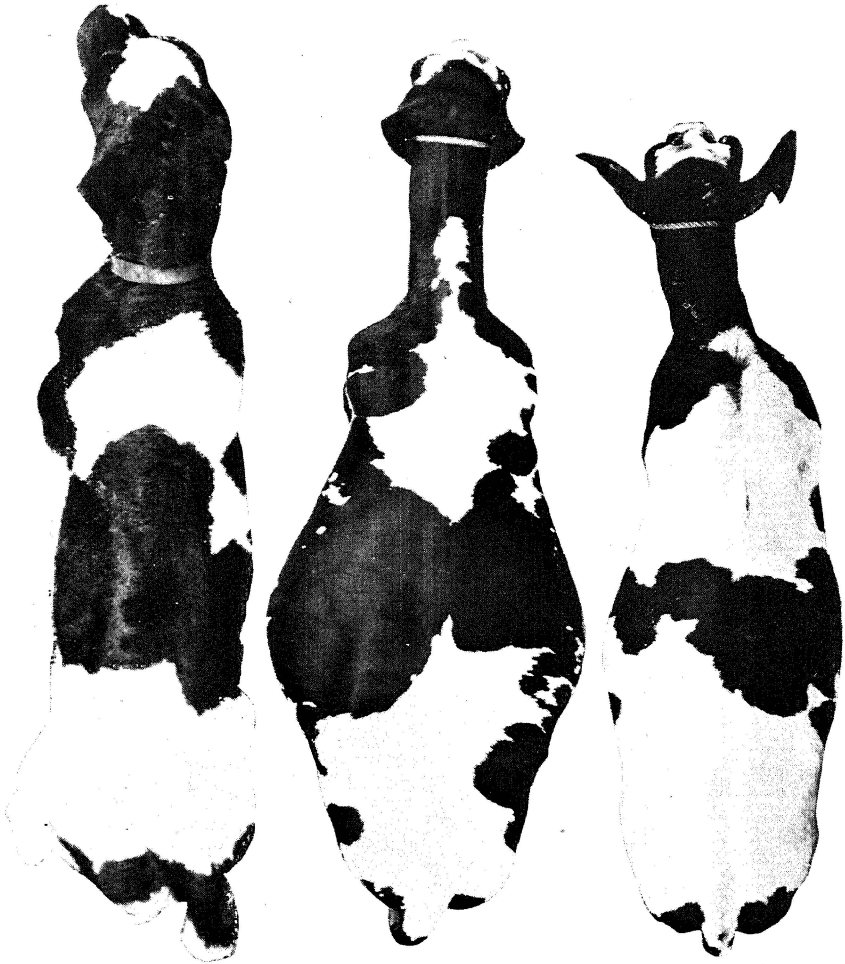
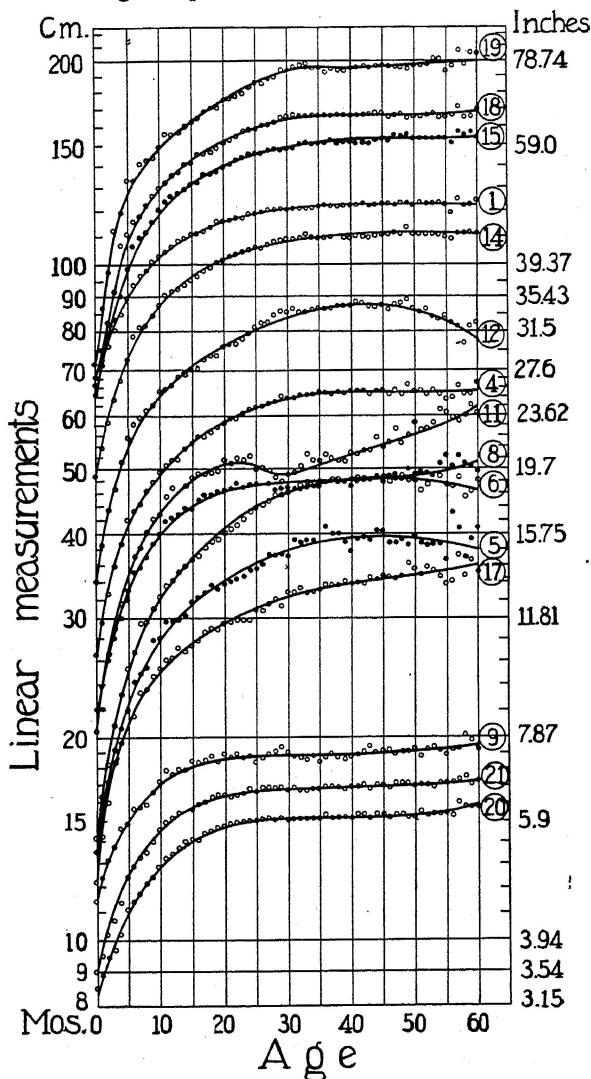


Figure 5.—Change of form with age. A comparison of top views of calf, heifer, and cow reduced to about the same length of body (withers to tail). Compare the relative lengths of neck with figure 23. Note the rectangular form of the calf as compared to the cow.

Figure 6.—The course of growth in linear dimensions with age (Jersey cattle). The numerals enclosed in circles refer to the measurements given in Table 1 as follows: 19 girth of paunch, 18 heart girth, 15 from point of shoulders to ischium, 14 from point of shoulder to point of hips, 1 height at withers, 12 from highest point of withers to a line between hips, 4 depth of chest, 11 length of neck, 8 length of head, 6 width of hips, 5 width of chest, 17 from hips to last rib, 9 width of forehead, 21 and 20 circumference of shin bone of hind and fore legs.

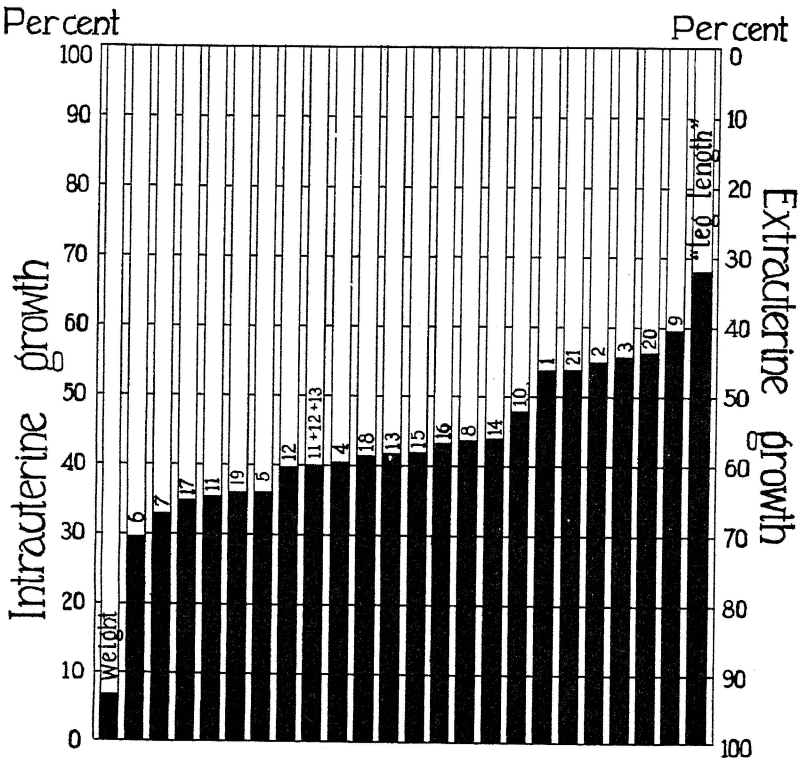
The measurements are here plotted against age, the ordinates being divided in geometrical progression. Different quantities which change at the same rate (e.g. \$100 and \$1000 when invested at the same rate of interest) when plotted on this type of paper give curves which are parallel. If the several measurements here presented were changing at the same rate, their curves would be parallel. But their curves are not parallel; therefore, they do not change at the same rate with age.



The steepest curve is that representing the width of hips (6); and the least steep curve is the curve of width of forehead (9). The width of hips

therefore increases at the highest *rate*, and width of forehead at the lowest rate (using the term "rate" in the sense of rate of interest).

Figure 7.—Amount of relative growth before and after birth, expressed as percentages of mature values (Averages of the Holstein and Jersey groups of cattle). The numerals on the tops of the columns refer to the measurements given in Table 1 as follows: 6, width of hips; 7, width of loin; 17, from hips to last rib; 11, length of neck; 19, girth of paunch; 5, width of chest; 12, from withers to hips; 11+12+13, length of whole body from horns to tail; 4, depth of chest; 18, heart girth; 13, from hips to tail; 15, from shoulders to ischium; 16, from hips to ischium; 8, from poll to muzzle; 14, from shoulder to hip; 10, circumference



of muzzle; 1, height at withers; 21 and 20 circumference of shin bone of hind and fore legs; 3, height at hips; and 9 width of forehead. "Leg length" equals height at withers minus depth of chest.

In the graph the values of the measurements at 5 years (approximate maturity) are taken as 100 per cent and they are represented by the whole lengths of the rectangles including the white and black portions. The blackened portions of the rectangles represent the percent-

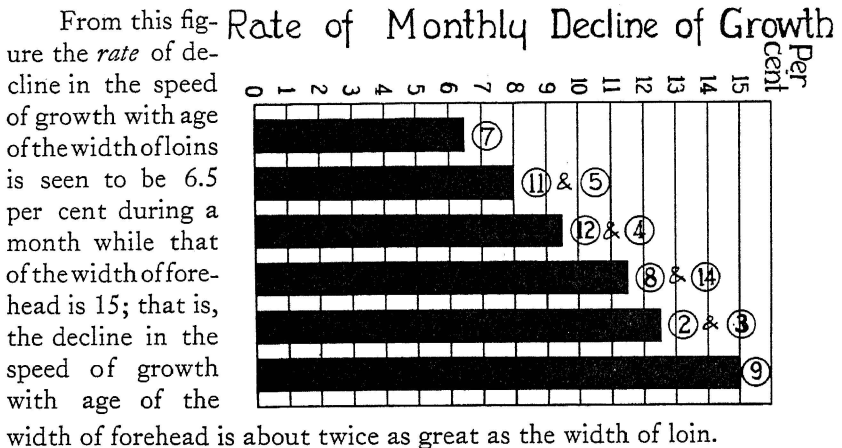
ages of growth *in utero*, before birth; the white portions represent the percentages of growth after birth.

From the figure the percentage of width of hips grown before birth is 30 and after birth 70; this represents one extreme. The width of forehead represents the other extreme, nearly 70 per cent of growth is before birth and only about 30 per cent after birth.

The enormous amount of growth before birth is very striking and impresses us with the rapidity at which the speed of growth decreases with age. We are also impressed with the differences at which the speed of growth of different parts decreases with age, and with the possible significance of these differences.

Figure 9.—A comparison of the monthly rates of decline of the speed of growth with age of some of the parts measured. The numerals on the top of the columns refer to the measurements given in Table 1 as follows: 7, width of loins; 11, length of neck; 5, width of chest; 12, length of trunk; 4, depth of chest; 8, length of head; and 9, width of forehead.

The speed of growth declines with age, and the changes of form with age are due, as already pointed out, to differences in the rates of decline of growth in different directions. The heights of the columns represent the actual *rates* of decline in the measurements represented.



We have shown elsewhere³ that the course of growth of the dairy cow may be roughly represented by the equation

$$M = A - Be^{-kt}$$

in which *M* is the value of the given measure at the age *t*. The reader may be interested to know that the heights of the rectangles for the several measurements represent the values of 100 *k* of the respective

measurements. 100 k represents the monthly percentage decline in growth, when the decline is computed from moment to moment.

Instead of expressing changes of growth in terms of rate or per cent of "decline" we may express the changes in terms of rate or per cent of "persistency", that is the per cent which growth made during any one month is of the growth made during the preceding month. The percentage of "persistency" is the difference between 100 and the percentage of decline. Thus the percentage of decline in growth of loins (100k) is 6.5. Therefore the percentage of persistency is $100 - 6.5$ or 93.5. That is, the growth in width of loins during any month is 93.5 per cent of the growth during the immediately preceding month. In the case of width of forehead, the persistency is $100 - 15$, or 85 per cent. That is the growth of width of forehead during any one month is 85 per cent of the growth during the preceding month. Thus the persistency of growth of width of forehead is less than the persistency of growth of width of loins. It should be clearly understood that these values are approximate, because growth is not changed strictly uniformly with age, and besides, there is a small mathematical error (which we cannot discuss here) inherent in this method of computing "persistency" values per month.

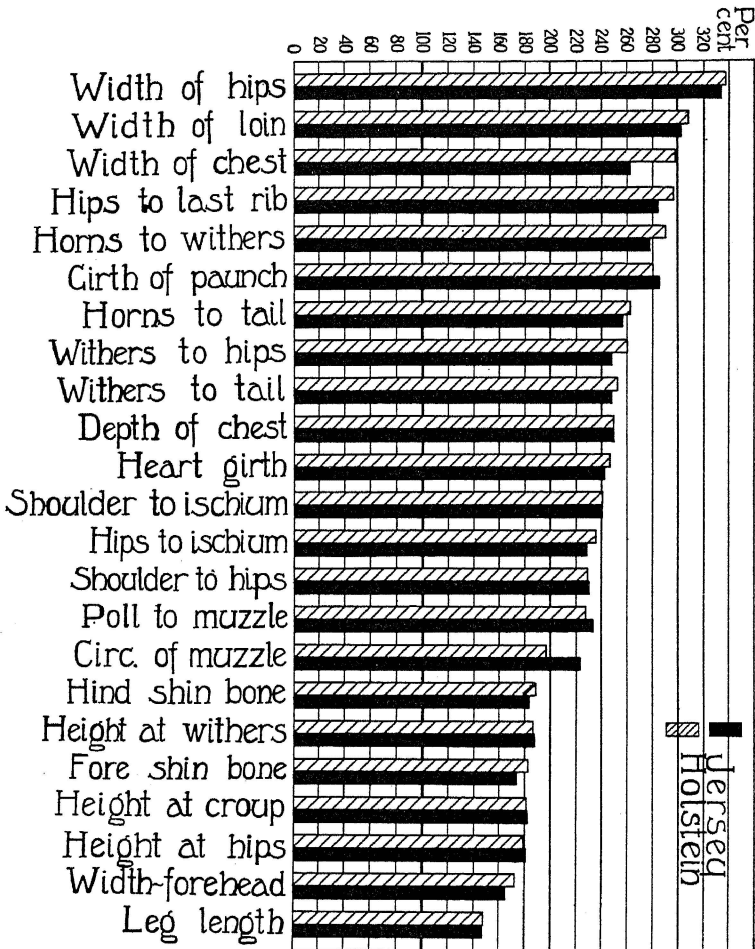
Figure 8. (Opposite page)—Amount of relative growth before and after birth expressed as percentages of the value at birth.

In this figure the values of the measurements at birth are represented as 100 per cent, and the values at 5 years (approximate maturity) are represented in terms of percentages of the birth values.

As shown in the figure the ratio that the width of hips of the mature cow bears to the value of this measurement at birth is 340; that is the mature value is 3.4 times the birth value, or 340 per cent of the birth

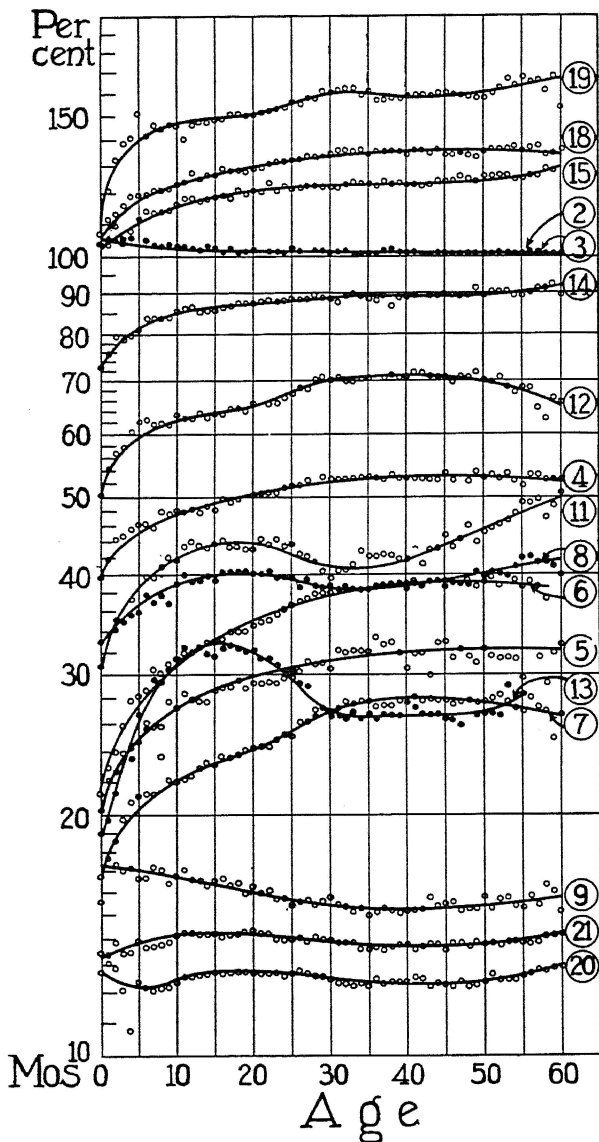
value. At the other extreme are shown width of forehead and length of leg which at maturity are only about 1.5 times, or 150 per cent, of the birth values.

This figure represents the same facts that were shown in figure 7 but in a different form and is given only to further emphasize the very con-



siderable growth made before birth and the consequent rapid decrease in the speed of growth with age; also to emphasize the differences in the relative rates of decline of growth with age of the different parts of the body.

Figure 10.—Relative change of form with age plotted on semi-logarithmic paper. The numerals enclosed in the circles refer to the measurements given in Table 1 as follows: 19, girth of paunch at end of



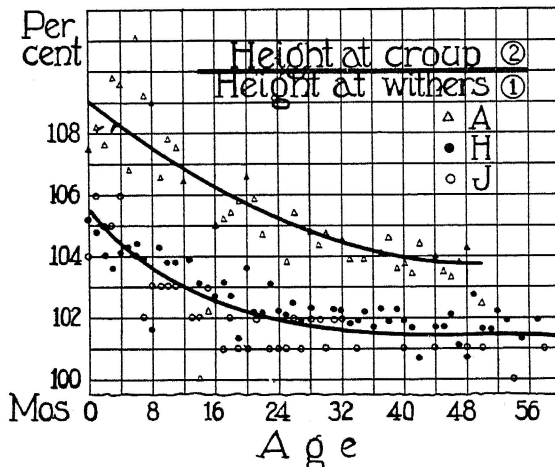
last rib; 18, heart girth just behind elbow joint; 15, from point of shoulders to ischium; 2, height at highest point of croup; 3, height at hip points; 14, from point of shoulder to point of hips; 12, from highest

point of withers to a line between hips; 4, depth of chest; 11, length of neck; 8, length from poll to point of muzzle; 6, width of hips; 5, width of chest; 13, from a line between hips to tail; 7, width of loin; 9, width of forehead; 21 and 20 smallest circumference of shin bone of hind and fore legs.

The values of the several measurements at different ages were divided by the height at withers at the corresponding ages, and the resulting quotients multiplied by 100 were plotted on paper, the ordinates of which are divided in geometric progression and abscissae in arithmetical progression. On this paper magnitudes changing at the same *rate* are represented by parallel lines, and the deviations from parallelism indicate the differences in the rates of change of the magnitudes. This graph, therefore, indicates the relative change in the ratios of the several measurements, and consequently by definition, the changes of form with age.

Having convinced ourselves that the form of the heifer changes with age, and having obtained a bird's eye view of the nature of the changes, we next proceed to a study of the changes with age of the ratios of the individual measurements to some one measurement taken as a standard for the corresponding ages. Height at withers is the standard used for the majority of the ratios inasmuch as height at withers is the easiest and most accurate measurement to take, and because our data on height at withers are based on the largest number of animals.

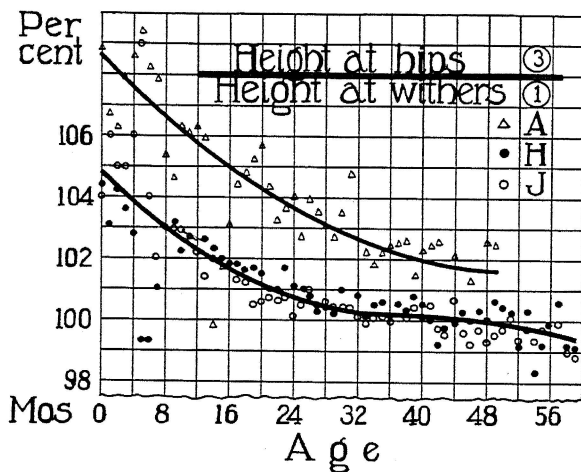
Figure 11.—Ratios of height at croup to height at withers (compare with figure 1).



At birth the height at croup is 106 per cent of height at withers, while at 5 years it is 101 per cent. This relative decrease by 5 per cent of the height at croup as compared to height at withers with age may be

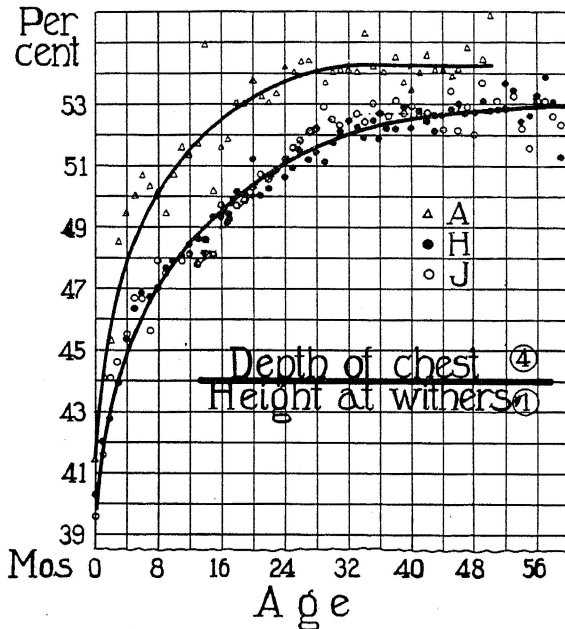
due to the relative increase in the weight of the hind quarters as compared to the front quarters with age. It is a principle of mechanics that the weight which a column can support varies inversely with its height; from which it follows that in increasing the weight of a structure supported at its ends by columns, one end of which is heavier than the other, the height of the columns supporting the heavier end should not be increased to the same extent as the height of the column supporting the lighter end if the relative strength of the two ends of the structure are to be maintained. The lag in the increase in height at croup as compared to height at withers with age is therefore in accordance with mechanical principles if the differences in height are due to differences in the height of the legs which are the supporting columns. The immediate causes bringing about the differences in the relative rates of growth of the front and hind legs—assuming that the differences in height are due to differences in length of legs—can only be guessed; one possibility is that the quarter of relatively greater increasing weight with age offers a greater resistance to the process of growth than the lighter quarter; another possibility is that the difference in the rates of growth of the two sets of legs are due to hereditary differences developed in the course of evolution because animals having this peculiarity of development had a better chance of survival.

Figure 12.—Ratios of height at hips to height at withers. This curve is very similar to the preceding one of the ratios of height at croup to height at withers. As the animal gets older the hind quarter tends to



sink as compared to the front quarter. The possible significance of the relative decline of the hind quarter as compared to the front quarter was given in the legend for figure 11.

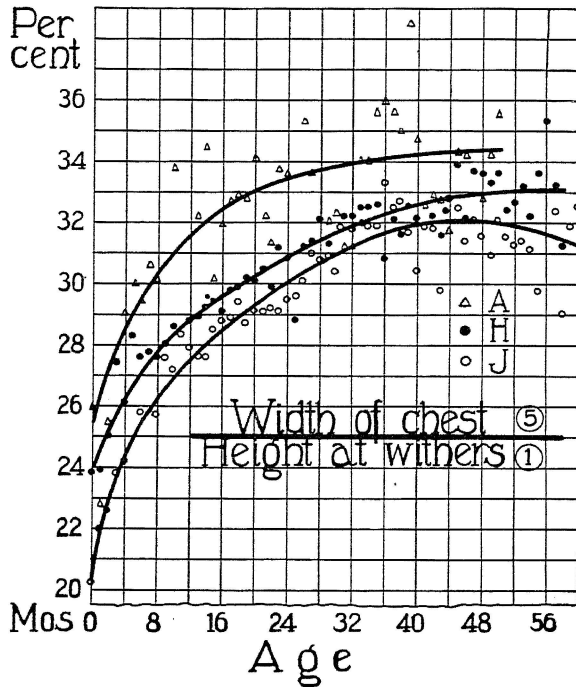
Figure 13.—Ratios of depth of chest to height at withers. The height at withers is the sum of the depth of chest and the length of the front leg. This figure plainly shows that the depth of chest grows faster than the length of leg. If the speed of growth of depth of chest and length of leg declined at the same rate with age, then of course the curve would be horizontal. The mature cow is shown by the curves to be about 13 per cent deeper in the chest as compared to height at withers than is the calf. (That is, the depth of chest of the calf is shown to be 40 per cent of height at withers whereas in the mature cow this is 53 per cent, a difference of 13 per cent).



The reader will note that the Ayrshire cow has greater depth of chest (or is shorter-legged) than the Jersey and Holstein cow, that is, the Ayrshire is a somewhat blockier animal. However, before drawing final conclusions, the reader must bear in mind the relative reliability of the data for the different breeds, (see Table 1) and the possibility of experimental error being responsible for the breed differences.

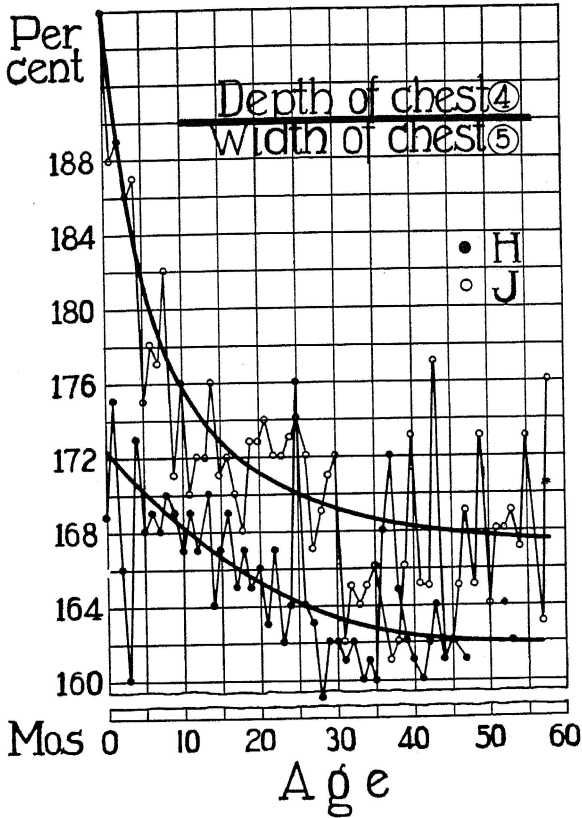
The reader may also note an abrupt rise in the ratios for the Jersey group between 16 and 30 months. This rise is probably due to the fact that these animals passed through their first period of gestation during this time, and gestation probably has a more stimulating effect on the growth of depth of chest than on length of leg.

Figure 14.—Ratios of width of chest to height at withers. The width of chest like the depth of chest grows faster than the height at withers. In other words, the calf is more slender in build than the cow.



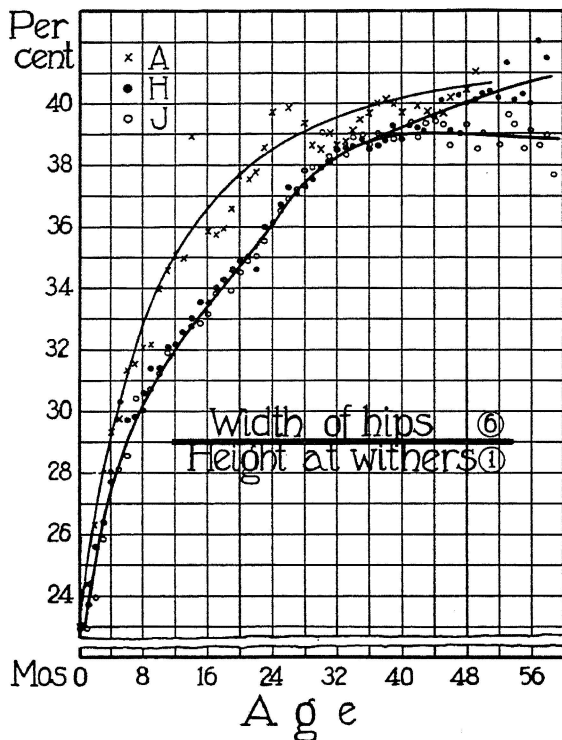
The reader will note here again that the Ayrshire has a wider chest relative to its height at withers or length of leg than has the Holstein or Jersey. The Holstein has a somewhat higher ratio than the Jersey. In other words, the Jersey appears to be the most slender or least blocky of the three breeds.

Figure 15.—Ratios of depth of chest to width of chest. This figure shows that the depth of chest decreases with age as compared to the width of chest. The mature animal has a wider chest as compared to its depth than does the calf.



It is remarkable that the Ayrshire calf should have a much deeper chest as compared to its width than the Jersey and the Holstein calf. Is it possible that a low depth of chest to width of chest ratio is characteristic of the dairy animal and that the early high ratio in the Ayrshire calf indicates a later historical development of the dairy characteristics in the Ayrshire than in the Jersey and Holstein breeds?

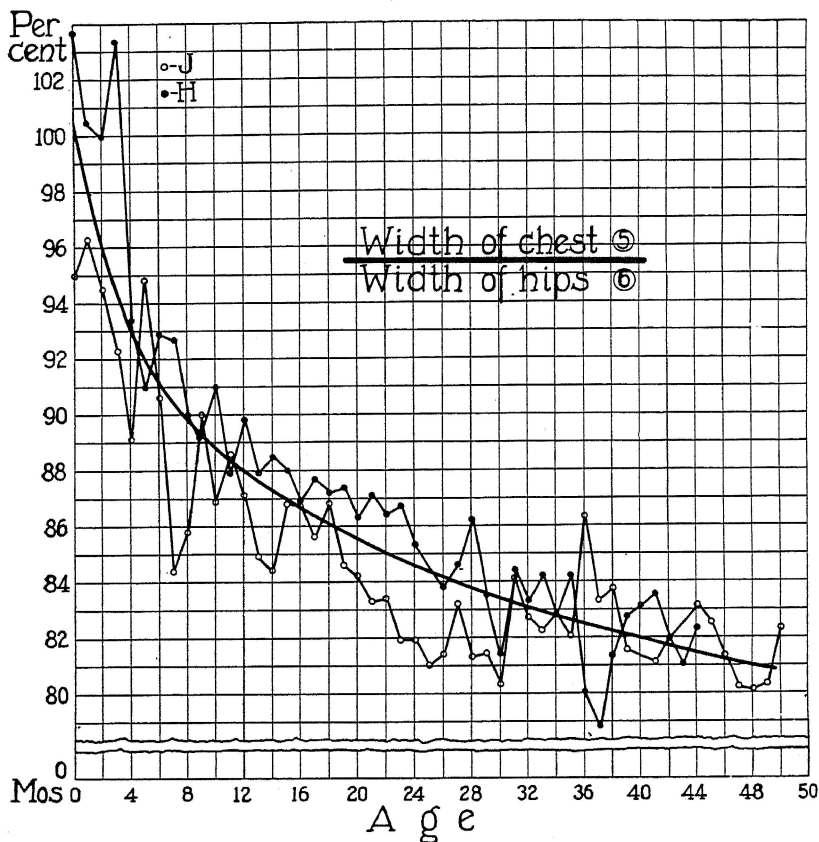
Figure 16.—Ratios of width of hips to height at withers. This ratio is seen to practically double itself during the course of growth, that is, compared to height at withers the adult cow has a width of hips which is about twice as great as in the calf. The cow is a very wide-hipped animal as compared to the calf. This is not surprising considering that the width of hips is one of the best measures of maternal development and that one



of the great differences between the adult and young animal is difference in sexual development.

It is interesting to note that a sharp rise occurs in the curve between 16 and 30 months—the period of gestation. Gestation appears to have a profound effect on the growth of width in hips. It is not mere adolescence, because the heifer becomes sexually mature at a much earlier age.

Figure 17.—Ratios of width of chest to width of hips. At birth the width of chest and width of hips have the same value—100 per cent. At 5 years the width of chest is only 80 per cent of the width of hips.



This graph therefore shows quantitatively the course of change of the rectangular shaped body of the calf into the triangular shaped body of the cow.

Figure 18.—Ratios of width of loin to height at withers. The characteristics of this curve are the same as that of the width of hips to height at withers ratio (figure 16) and for obvious reasons.

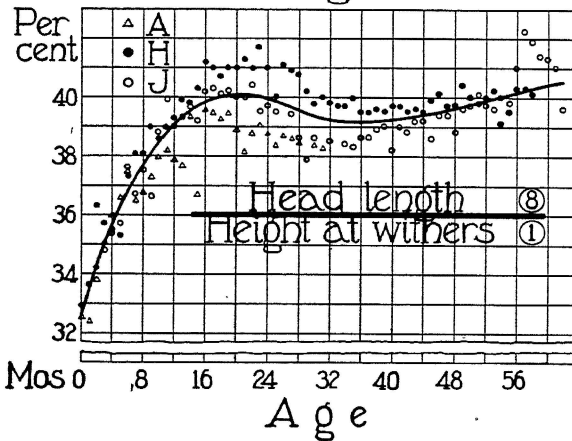
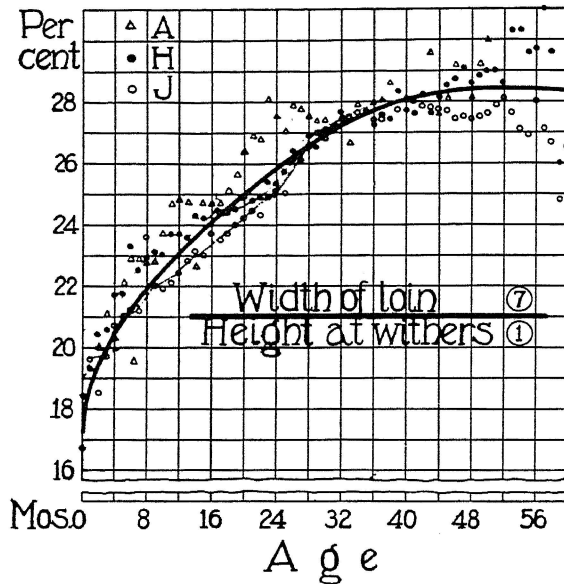


Figure 19.—Ratios of head length to height at withers. The adult cow is seen to have a longer head than the calf, as compared to height at withers. It is somewhat curious that these ratios decline between 16 and 30 months, the time of gestation. It appears that gestation stimulates a slightly more rapid growth in the components making up the height at withers, most probably the depth of chest, than the length of head (cf. Fig. 15).

Figure 20.—Ratios of width of loin to width of hips. These ratios appear to increase during the first month. From the second month on, the ratios decline steadily from 85 to 70 per cent, a net reduction of about 15 per cent. The slight rise between 28 months, the age of first calving, and 34 months, the age of second gestation, may have some significance.

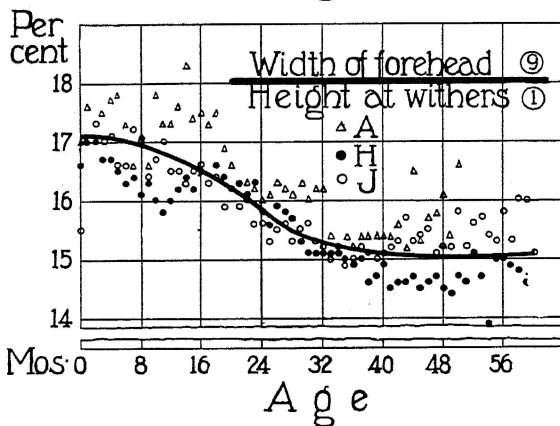
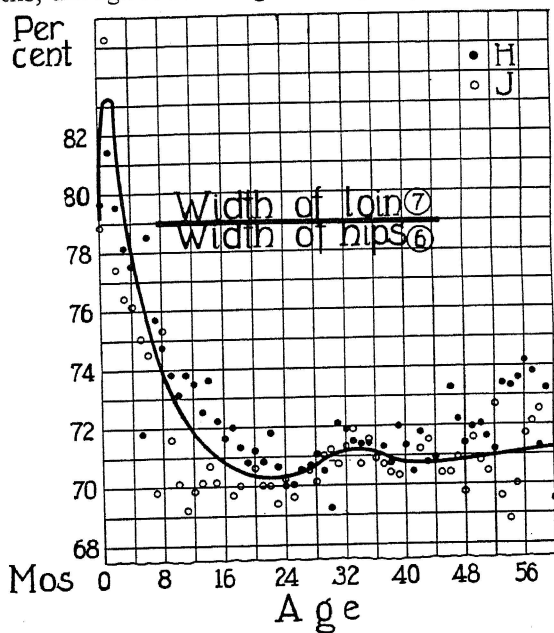
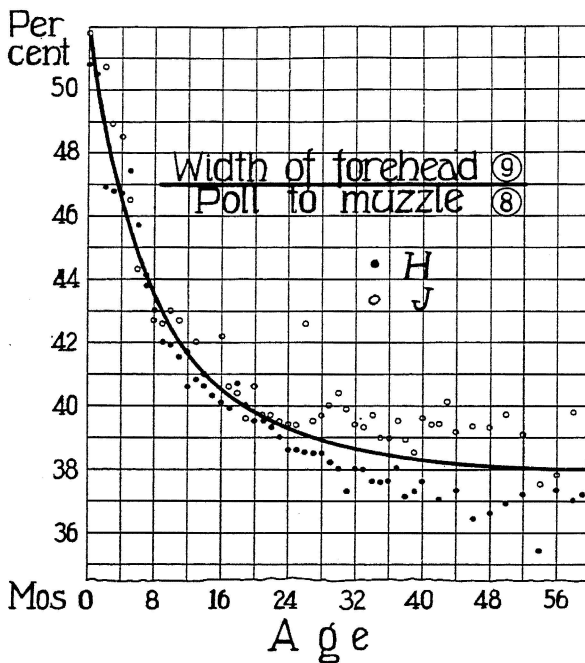


Figure 21.—Ratios of width of forehead to height at withers. The speed of growth of the width of forehead declines rapidly with age as compared to the growth in height at withers. The cow is a very narrow-headed animal as compared to the calf. (Continued on page 28)

The relatively rapid decline in the speed of growth of the head with age appears to be true for other animals; also man. Adult man has a relatively very small head as compared to the babe. It appears that provision is made very early for the protection of the central nervous system. In other words, animals with relatively undeveloped skull at birth have a smaller chance of survival than those of well developed skull with the result that the surviving population is of an early-developing skull type.

Figure 22.—Ratios of width of forehead to length from poll to muzzle. The head rapidly increases in length as compared to its width.



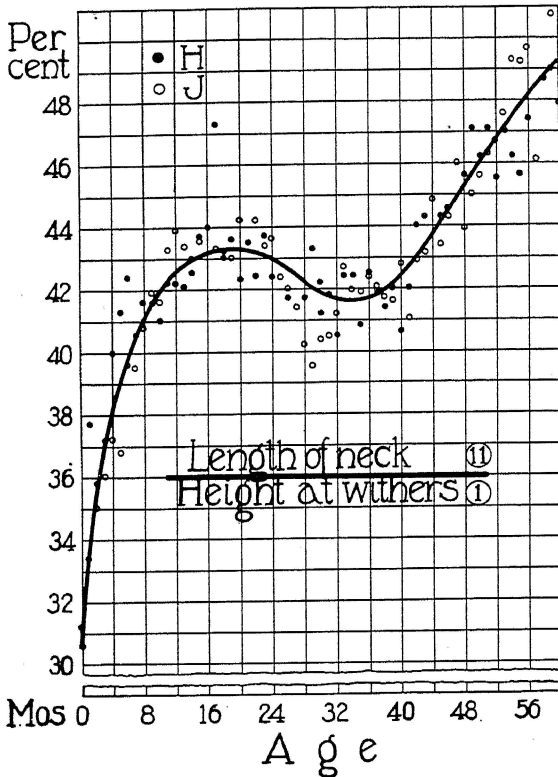
The cow is long and narrow-headed as compared to the calf. This is probably due principally to the fact that the head length measurement includes the parts of the face which are not parts of the skull proper.

Figure 23.—(Opposite page) Ratios of length of neck to height at withers. The first striking characteristic is the enormously rapid growth of the neck as compared to height at withers. (See Figs. 1 and 3).

The second striking peculiarity of this curve is the interruption of the relative growth of the neck between 16 and 33 months, (cf. curve 11 in Fig. 6) the age of the first gestation. It appears that gestation some-

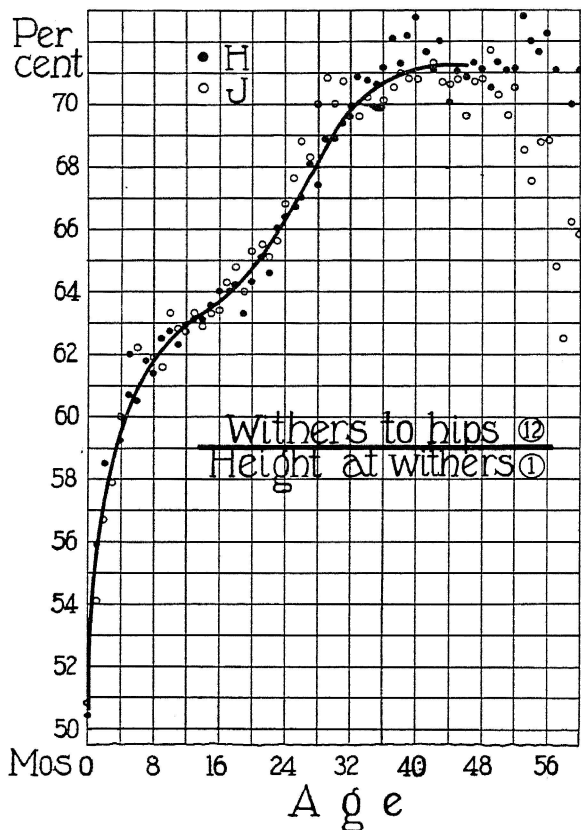
what interferes with the relative growth in the length of the neck as compared to height at withers, or, in fact, as compared to any other measurement.

The relative effect of gestation on the growth of the various parts is probably related to the relative importance of these parts to the animal. It may be that length of neck and length of head (Fig. 20) are relatively unessential and are neglected in favor of other more essential parts during the critical period of gestation.



The length of neck is a measure difficult to take accurately because a slight bending of the head changes the value of the measurement and the peculiarities of the curve may be thought to be due to experimental errors. However, the smoothness of the distribution of points, and the fact that the Jersey and Holstein data follow the same course, make the explanation of the bending of the curves due to experimental errors very improbable. The peculiarities appear to be real and inherent in the process of growth, and in the effect of gestation on growth.

Figure 24.—Ratios of withers to hips to height at withers. Up to eight months this ratio rapidly rises; that is the length of the body rapidly increases as compared to height at withers. This is what was found for the length of neck. After this age the similarities between these ratios and those in the preceding figure on the length of neck ratios cease. In the preceding figure on the length of neck, the ratios decreased after 15



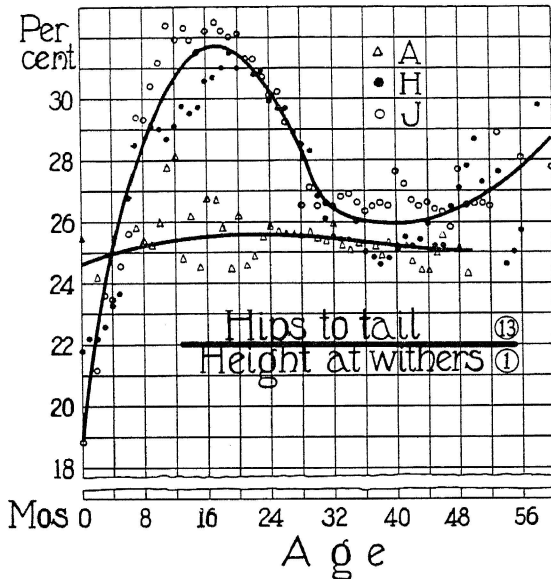
months while in this figure the ratios rapidly increase between 16 and 32 months, the period of gestation. Gestation therefore has a relatively high stimulating effect on the growth of the trunk.

The mature cow therefore has a relatively very long trunk (and neck) as compared to the calf, taking height at withers as the standard of comparison. Also, the growth of the length of the trunk is apparently profoundly influenced by gestation—gestation stimulates this growth.

Growth in length of neck and in length of trunk are oppositely affected by gestation.

There is a possibility that the rise between 16 and 32 months happens to coincide with the period of gestation by pure chance, and that these two are not causally connected. This question is therefore subject to further investigation. We express only an opinion which seems to us reasonable.

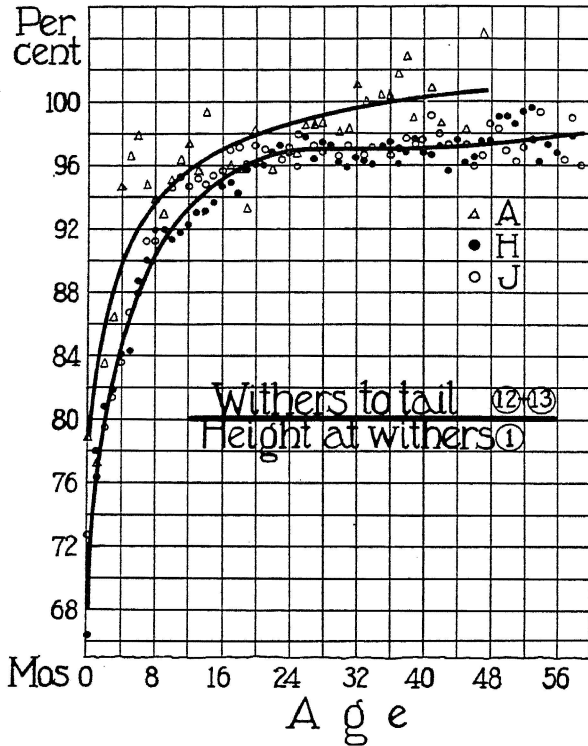
Figure 25.—Ratios of hips to tail to height at withers. The peculiarities of this curve are very similar to those of the curve for length of neck. (Fig. 23). There is some possibility that the decline during the



period of gestation is exaggerated by the mechanical pulling down of the abdomen.

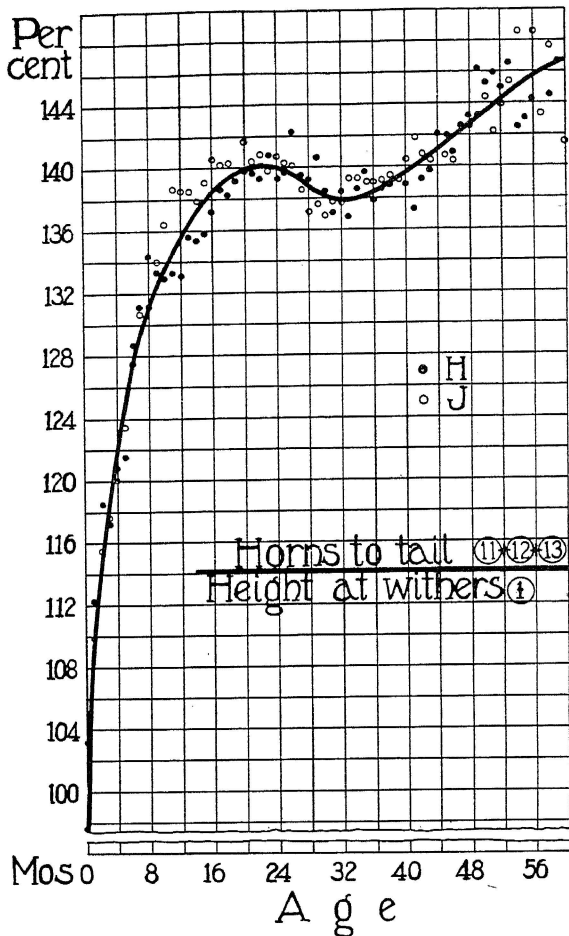
It is interesting to note that the Ayrshire data do not show this decline. However, this measurement is subject to much error, and the small number of Ayrshire animals represented (see Table 2) makes the Ayrshire curve unreliable. It should also be noted that the data of the Holstein and Jersey animals follow the same course.

Figure 26.— Ratios of withers to tail to height at withers. This figure shows that the length of the body proper of the calf is only two-thirds as great as the height, but at maturity the length is almost exactly the same as the height.



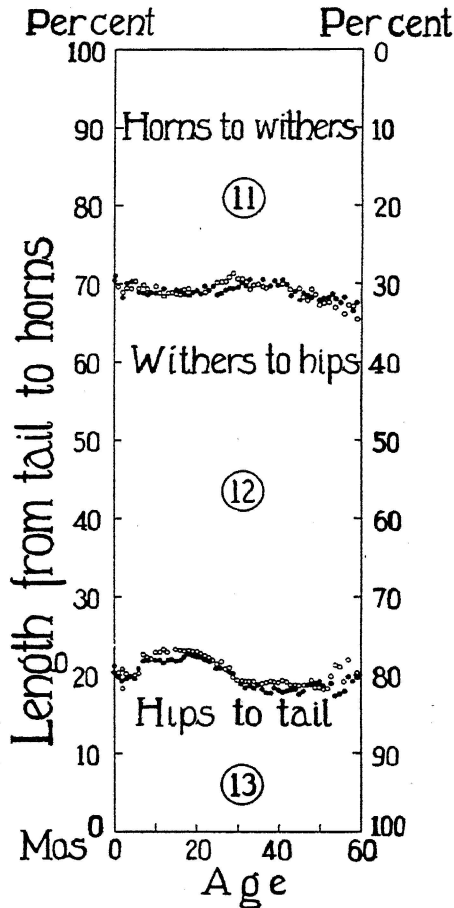
This also shows that the fluctuations in measurements 12 and 13 are in opposite directions, and that adding the two gives a tolerably smooth curve.

Figure 27.—Ratios of horns to tail to height at withers. The total length of the calf is slightly less than the height at withers (98 per cent). The length of the mature cow is nearly one and one-half times the height



at withers. The mature cow is therefore a very long animal as compared to the calf (see Figs. 2 and 3).

Figure 28.—The variation in the magnitude of the components making up the length of the cow. The whole length of the body from horns to tail, is taken as 100 per cent, and length of neck, trunk, and withers to hips are expressed as percentages of the total length at different ages. The relative magnitude of measurement 12 is greatest after

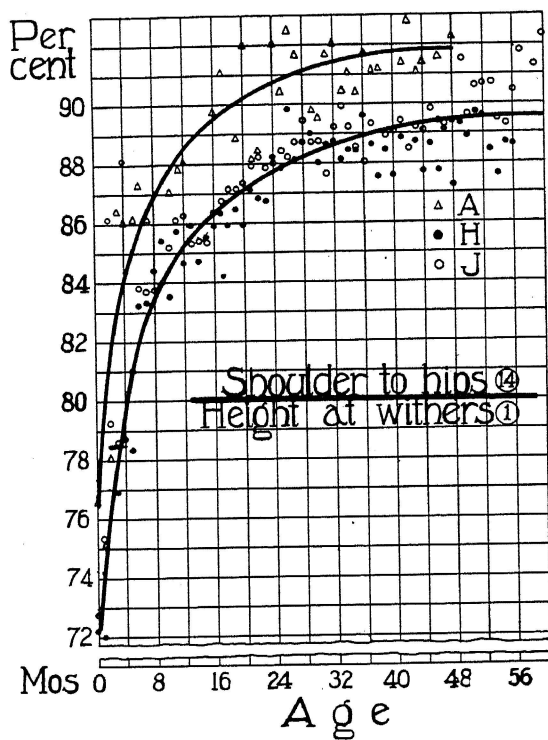


30 months when it is 52 per cent of the whole body, and it is least at about 15 months. The peculiar hump of measurement 13 at 15 months is very striking.

The graph may be roughly summarized by saying that 30 per cent of the length of body is due to length of neck, 20 per cent to distance from hips to tail, and 50 per cent to length of trunk.

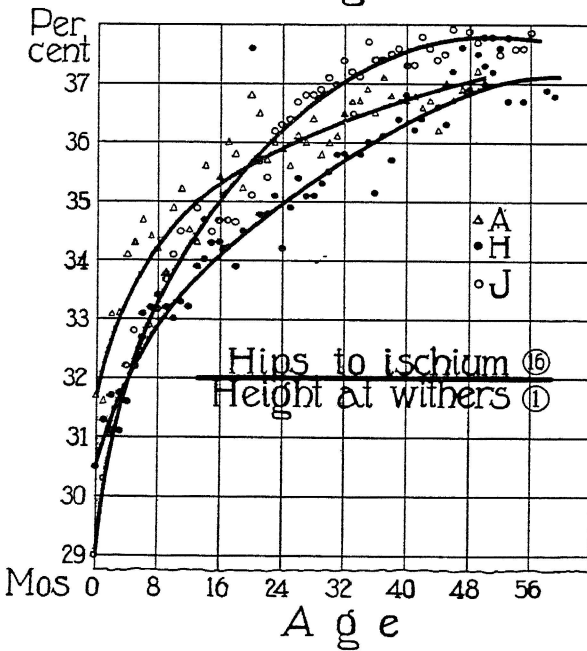
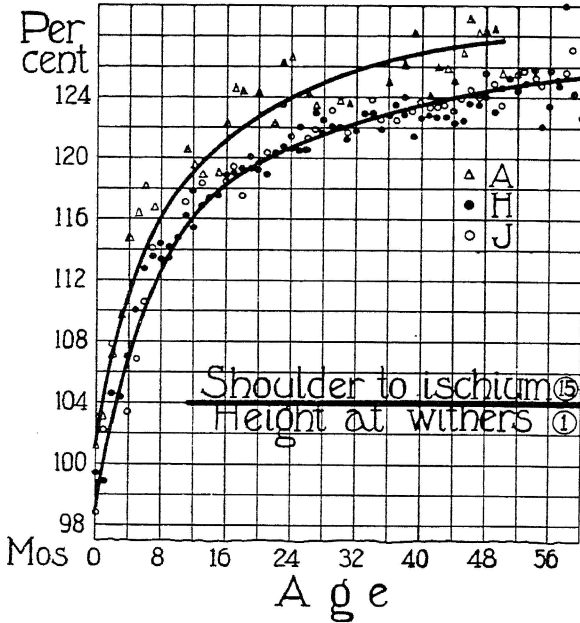
Figure 29.—Ratios of shoulder to hips to height at withers. These ratios increase from 72 per cent at birth to about 90 per cent at 5 years.

These ratios may be considered as supplementary to the ratios of measurement number 12 to measurement number 1 considered in Fig.



24, and they exhibit the same characteristics but in a modified form. The reader will notice a rather short rise between 16 and 32 months (the period of first gestation) for the Jersey data.

Figure 30.—Ratios of shoulder to ischium to height at withers. These ratios increase from 90 per cent at birth to 125 per cent at 5 years.



These ratios may be considered as supplementary to the ratios of measurements 12 + 13 to measurement number 1, considered in Fig. 26, and they exhibit the same general characteristics.

Figure 31.—(Bottom of opposite page.) Ratios of hips to ischium to height at withers. These ratios increase from about 30 per cent at birth to about 37 per cent at 5 years.

These ratios may be considered as supplementary to the ratios of measurement number 13 to measurement number 1 considered in Fig. 25. The general properties of the curves in Fig. 25 and 31 are different. Instead of the decline between 16 and 32 months shown in the curve of Fig. 25, there is here an especially striking rise for the Jersey group of cows.

Figure 32.—Ratios of hips to last rib to height at withers.

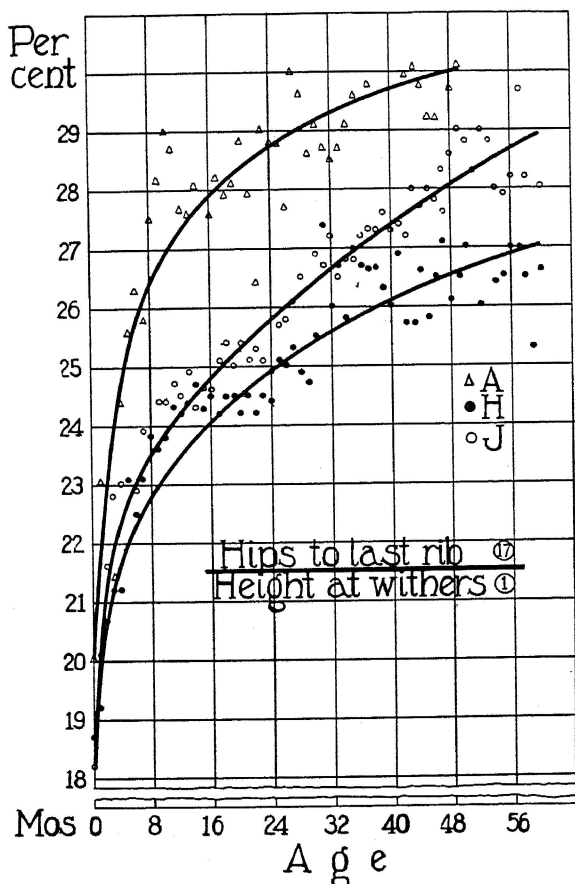
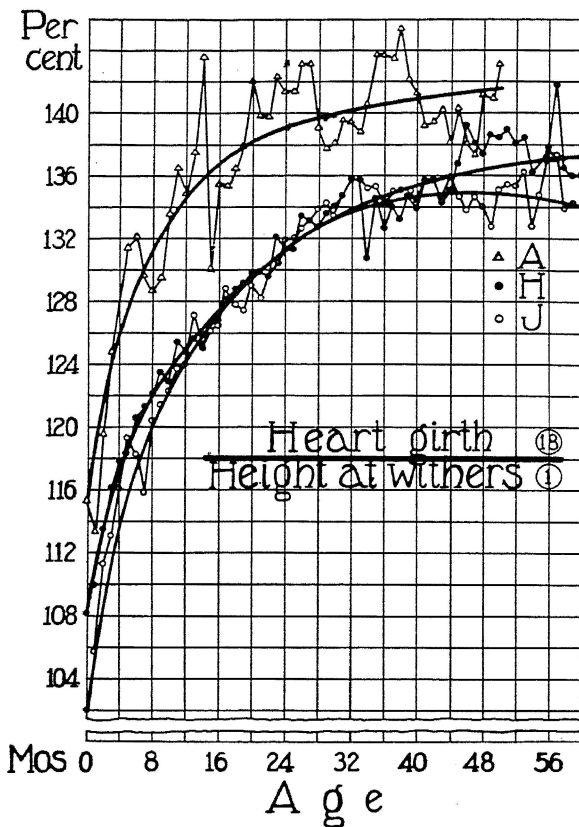


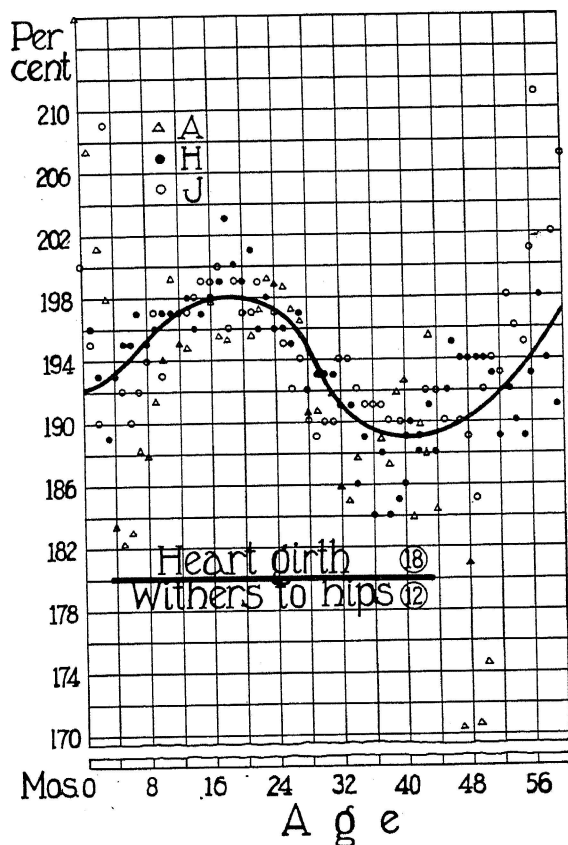
Figure 33.—Ratios of heart girth to height at withers. These ratios may be considered as indices of build in the sense of expressing stoutness or blockiness in analogy to comparisons between the heart girth to stature ratios used to express build in man.⁴ Evidently the adult



cow is of very much blockier build than the calf. The ratios rise from 103 to 137 per cent. It is also interesting to note that the Ayrshire is a blockier animal than the Jersey or the Holstein (compare to Figs. 13 and 14).

Figure 34.—Ratios of heart girth to withers to hips. These ratios may also be considered as indices of build in analogy to comparison between the heart girth and length of trunk in man which is used to estimate the relative stoutness in man⁴.

Using these ratios as indices of build, it is seen that the stoutness or blockiness of the heifer increases up to 16 months; then it decreases.



The decrease coming as it does during the period of gestation when measurement 12 rapidly increases (See Fig. 24), the apparent decline in the blockiness during this time is evidently due mainly to the rapid growth in the length of the trunk. Gestation appears to stimulate growth of length of trunk to a greater extent than it does the heart girth. (See also Figs. 12 and 14).

Figure 35.—Ratios of girth of paunch to height at withers. The most rapid rise in the ratios occurs during the first four months after birth in preparation for the change in feed from milk to roughages. The rise between 20 and 30 months is obviously due to gestation.

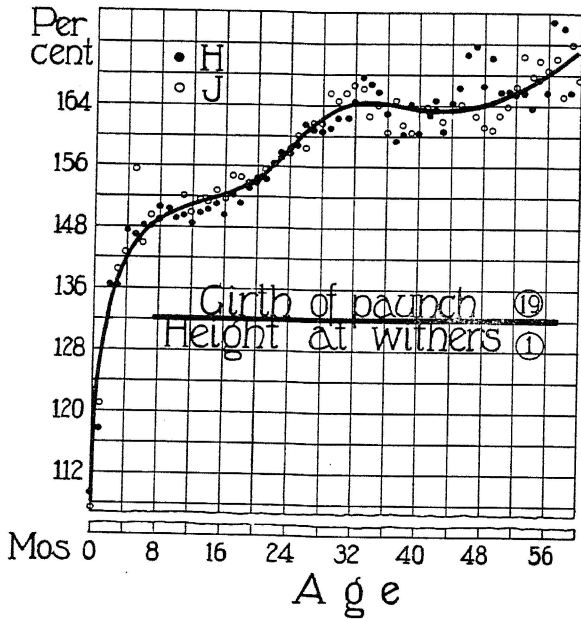
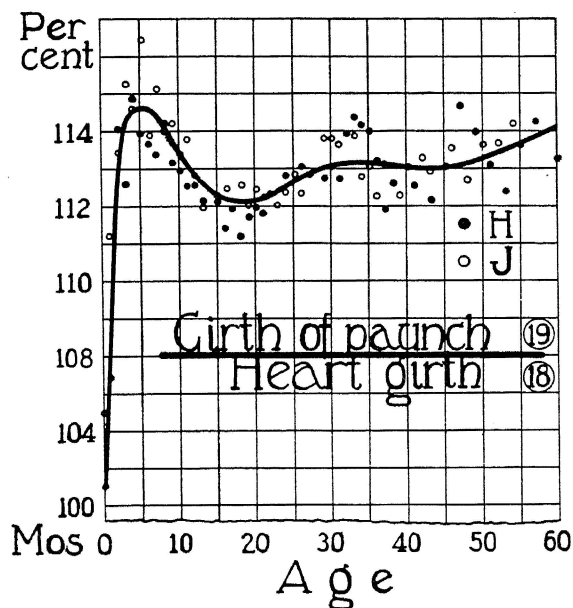


Figure 36.—Ratios of girth of paunch to heart girth. The girths of paunch and of chest are the same in the calf at birth. The ratio rises to about 123 per cent in the first five months which is the maximum.



Then there is another rise between 16 and 30 months due to gestation. Between 5 and 15 months, however, the chest girth seems to increase more rapidly than the girth of paunch as seen by the decline in the ratio curve.

The relative increase of paunch as compared to chest girth further adds to the triangular effect of the animal mentioned in the legend for Fig. 17.

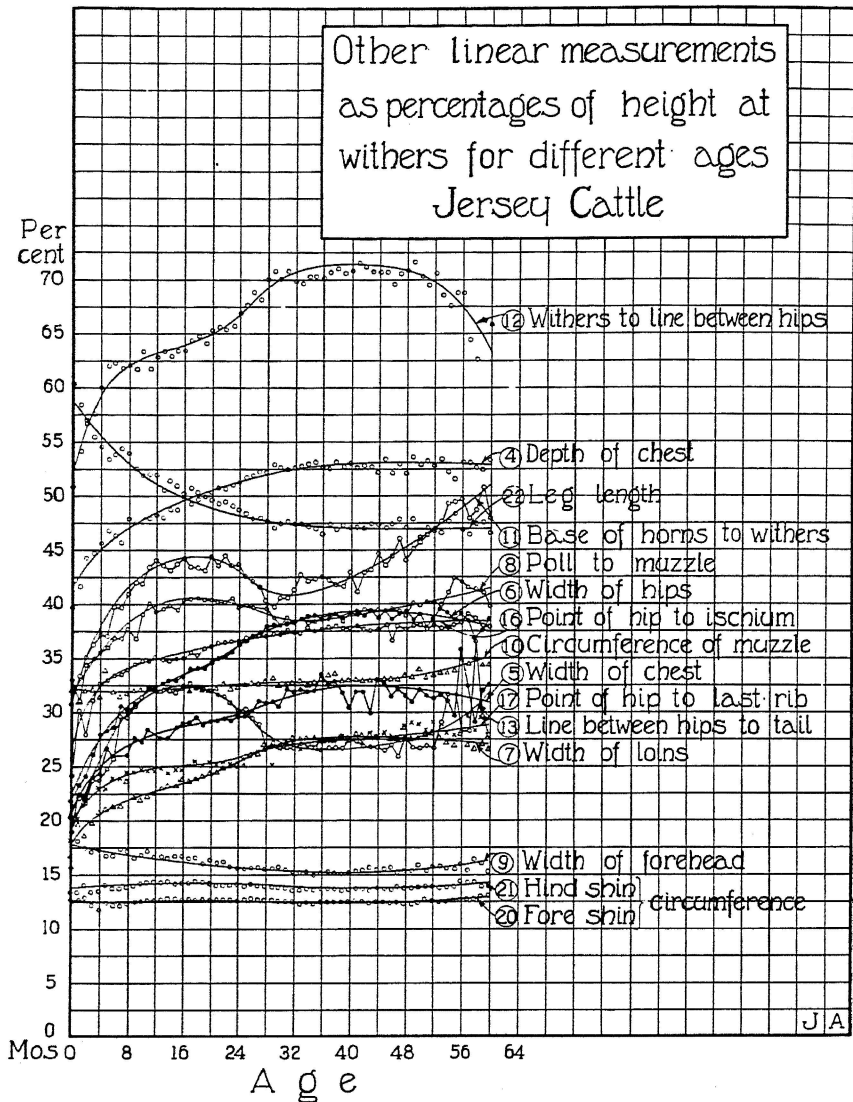
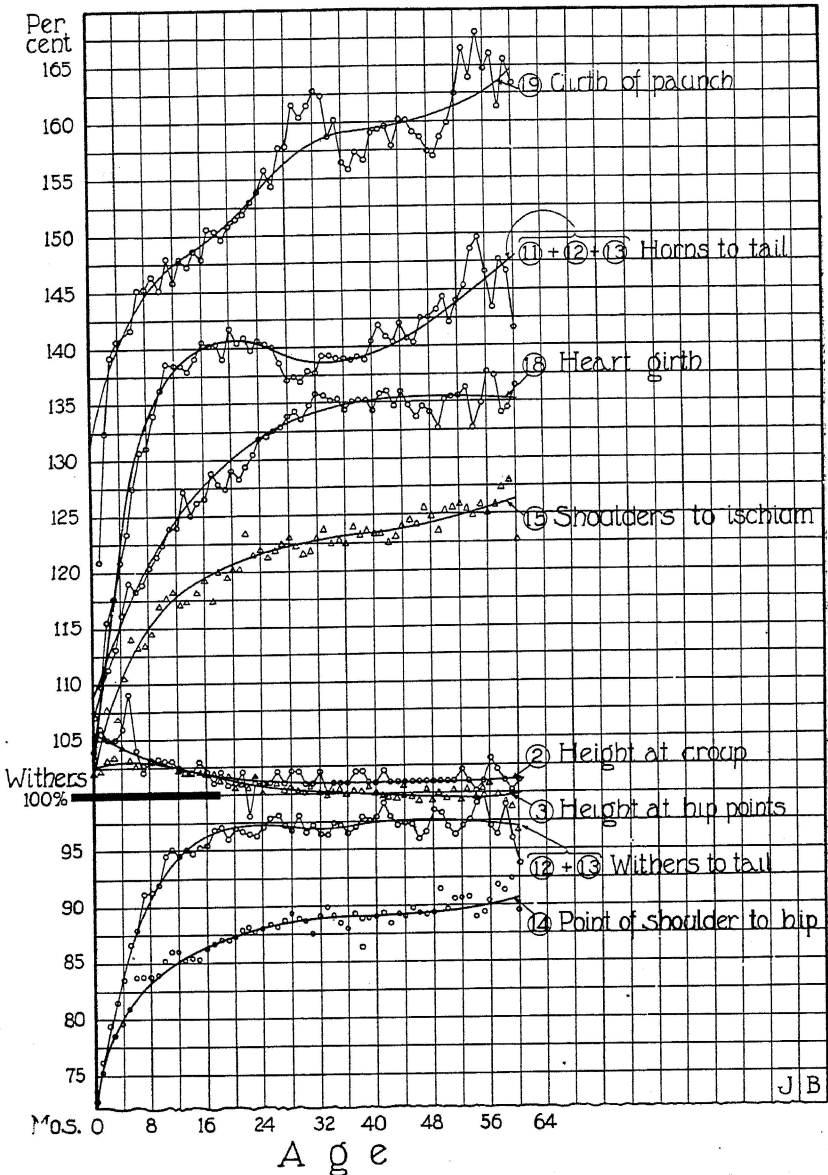
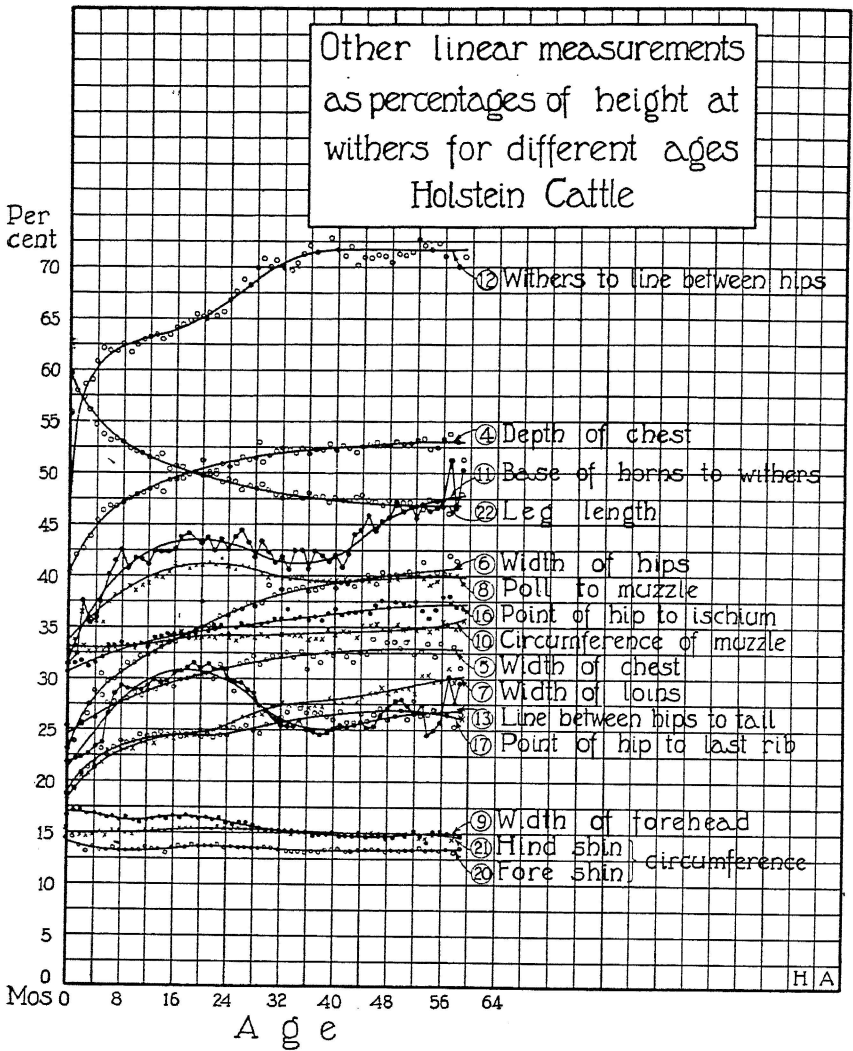


Figure 37a and Figure 37b.—In these figures the ratios of the several measurements to height at withers of the Jersey group of cows were brought together for purposes of comparison. The reader should compare the curves in these charts to the curves in Fig. 10.

In these charts the curves represent arithmetical differences in the values of the ratios from month to month because the divisions on the paper are in arithmetic progression. The divisions on the paper in Fig. 10 are such as to show *rates* of increase or *ratios* of increase from month



to month. A 10 per cent change from one month to another is shown by the same slope or the same steepness in Fig. 10 regardless of whether the absolute values are large as in girth of paunch, or small as in width of forehead. But a 10 per cent change in girth of paunch in Figs. 37a and 37b show a much steeper slope than on a small value such as width of forehead.



Figures 38a and 38b.—These curves are the same as those in Figures 37a and 37b, but of the Holstein group of cattle. (Fig. 38b is on the opposite page.)

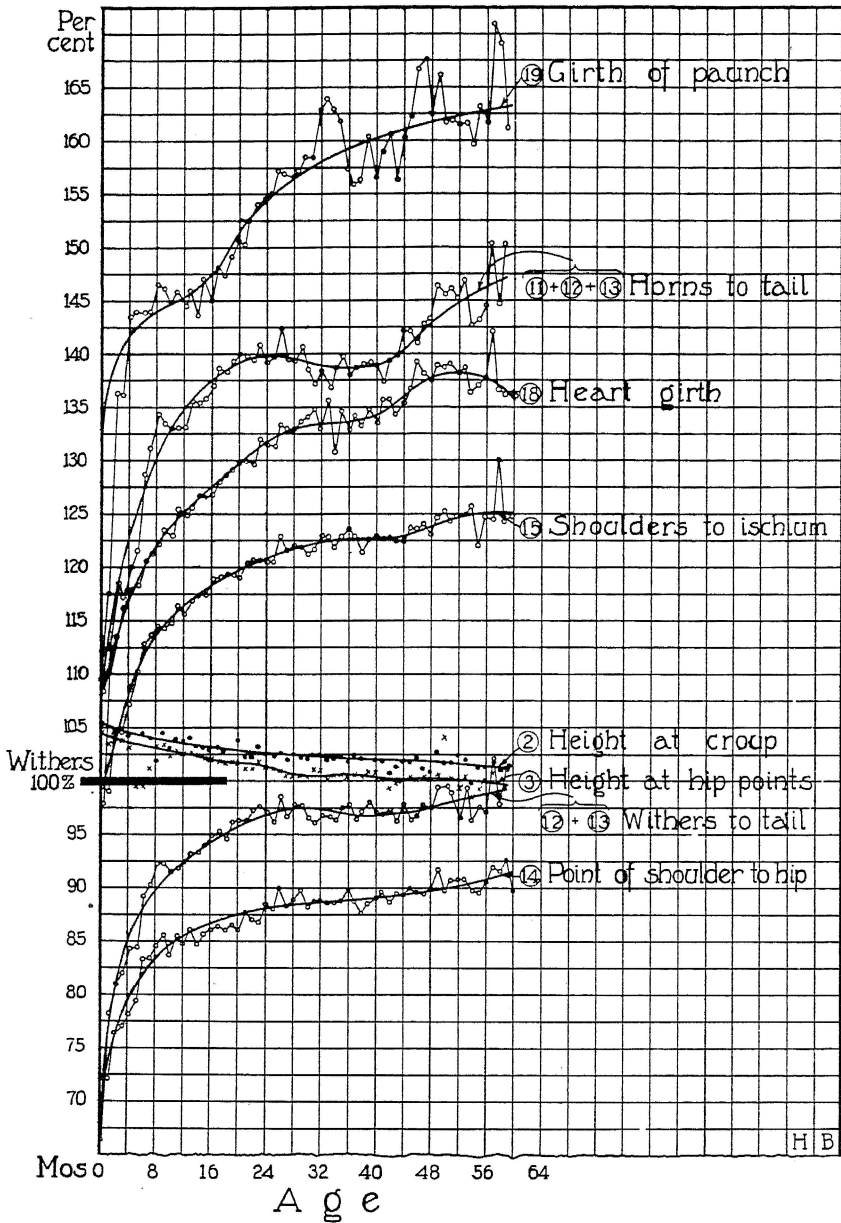


Figure 39.—(Opposite page.) Relation between weight and linear measurements at different ages. While the change of form with age is brought out by a study of the ratios between linear measurements, some additional information may be obtained by a comparison of weight to linear measurements. This figure is intended to show something of this relation.

From a principle of geometry, in similar homogeneous bodies the weight of the body increases with the cube of its linear dimensions. According to this principle, if growth was not accompanied by change of form the ratios of weight to the cube of the linear measurements would be constant for all ages; that is, the curve representing these ratios would be horizontal. That this is *not* the case is shown in this chart.

The curve passing through the triangles shows the changes with age of the ratios of weight to the cube of height at withers and width of hips. It is evident that the weight increases faster than the cube of height at withers, and slower than the cube of width of hips, indicating that height at withers grows slower than some other linear measurements and that width of hips grows faster than some other linear measurements with increasing age.

The best *empirical* relation between weight and height at withers is obtained when height at withers is raised to the 4.1 power and between weight and width of hips when the width of hips is raised to 2.3 power. These ratios are represented by the curves passing through the circles.

But even if height is raised to the 4.1 power and width of hips to the 2.3 power we do not get absolutely horizontal lines. The up and down movements of the ratios indicate some important changes. The high point at 28 months is probably due to gestation and the decline to the loss in calving and to lactation. The high point at 8 months roughly coincides with the maximum of the second cycle discussed elsewhere⁵. No doubt many changes take place in weight such as those due to the growth of the alimentary tracts in changing from the nursling to the consumer of roughage which do not affect the linear measurements. Other ideas will perhaps suggest themselves to the reader interested in interpreting these curves.

Note: Zeros were omitted in the ratios. The decimal point should be moved 6 places to the left for the $\text{wt}/(\text{Heart girth})^3$ ratio; 3 places for the $\text{wt}/(\text{Hips})^{2.3}$ ratio; 8 places for the $\text{wt}/(\text{Height})^{4.1}$ ratios; 3 places in the $\text{wt}/(\text{Hips})^3$ ratios and 4 places for the $\text{wt}/(\text{Height})^3$ ratios.

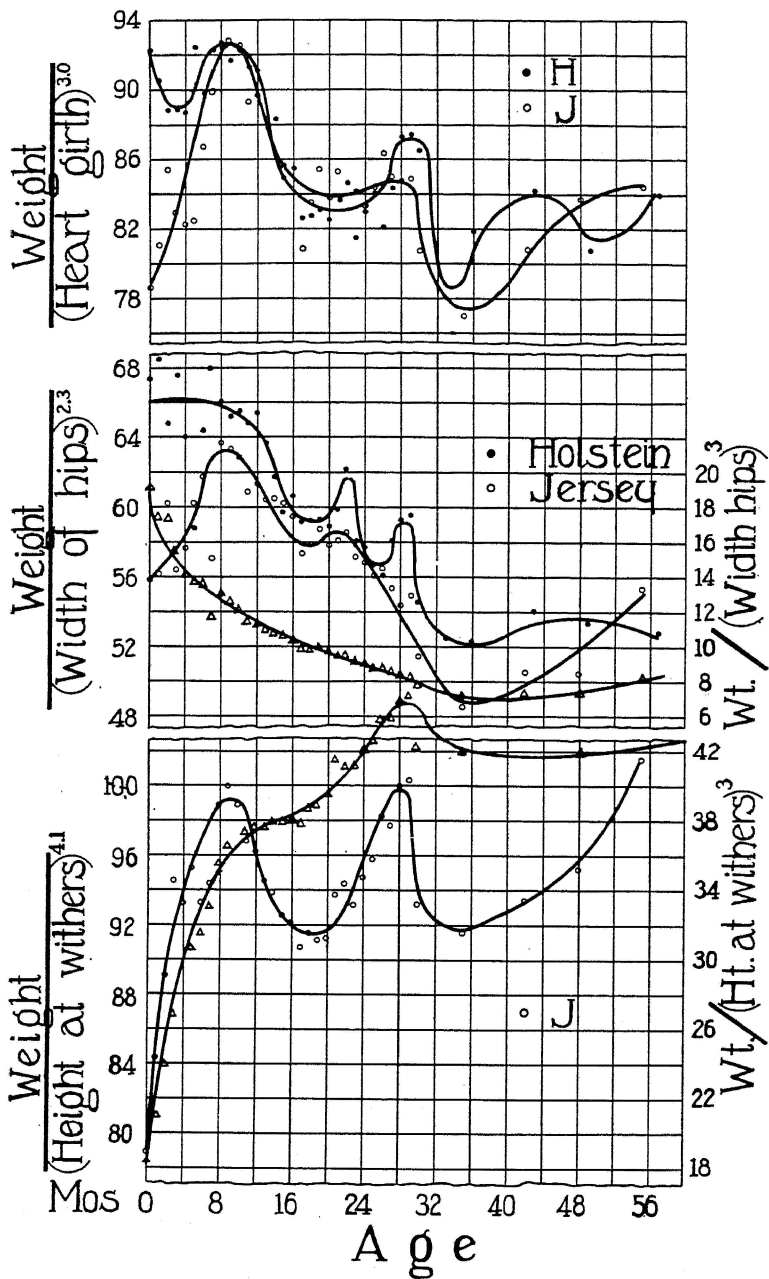
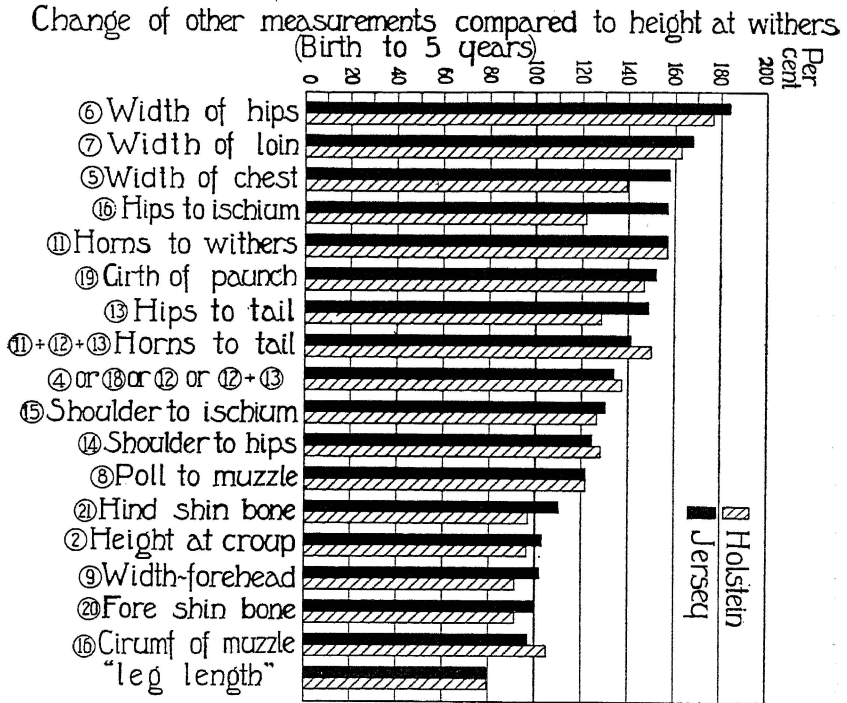


Figure 40.—Relative change of other measurements from birth to maturity as compared to the change in height at withers from birth to maturity.

Taking the change in height at withers from birth to maturity as 100, the relative changes in the other magnitudes are represented by the



heights of the columns in this figure. Thus the change of width of hips from birth to maturity is 190 as compared to 100 the change in height at withers from birth to maturity, and so on for the other values.

This chart may be taken as a summary of the changes of form with age of the dairy cow showing as it does in a compact form the *relative* changes in growth during the extra-uterine period of growth.